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Experimental and Numerical Study of Photo Voltaic Thermal Phase Change Material Heat Transfer Augmentation with Encapsulation of Embedded Material/Fins

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ABSTRACT

Nonconventional energy sources like natural gas, coal, fossil fuels and petroleum are using extensively, leads to clean energy / renewable energy importance. Power generation with burning of fossil fuels can be changed using solar energy input source. Solar radiation incident on Photo voltaic Thermal (PVT) panel raises its temperature which tends to decrease the electrical output. Heat enhancement in Photo voltaic Thermal (PVT) panel can be reduced by attaching Phase Change Material (PCM) container on rear side of PV panel which increases the PVT efficiency. Novel technique and promising media for better thermal energy storage using PCM with fins, porous materials. Thermal conductivity of PCMs was low creates problem for energy storage and rate of retrieval. Improvement of thermal conductivity in PCMs and heat transfer enhancement can be done efficiently with the help of fins and porous materials of different designs. Present study provides optimum design of PCM container depth, fin height along with length of fin. Enhancement of heat transfer in Photo voltaic Thermal- Phase Change Material (PVT-PCM) will done by addition of Nano particles (Tio_2, Sio_2 and Al etc.)of high thermal conductivity along with PCM. Porous materials / fins can be made with metallic based materials nickel, copper, aluminum and carbon materials like graphite. These porous materials gave good results and efficient in heat transfer / thermal conductivity enhancement by 50–600 times than the conventional one. This paper gives the recommendations and conclusions to discuss research gap in this area PCM heat transfer enhancement to reduce the PVT panel temperature.

Keywords: PVT, fins, PCM, heat transfer, porous materials.

INTRODUCTION

Sun solar radiation incident on the Photo voltaic Thermal (PVT) cell will convert only a fraction of energy in to electrical power. Maximum amount of energy was transformed in to heat and tends to raise Photo voltaic (PV) cell temperature thereby reduction in solar energy to cell power generation capacity efficiency. The present work gives the results of Photo Voltaic (PV), Photo voltaic – Phase Change Material (PV-PCM) and Photo voltaic – finned PCM systems to extract the hotness from PVT Panel. PCMs using latent heat energy can be designed effectively and efficiently with better energy density than that of sensible heat storage PCMs. But in latent storage PCMs charging and discharging is main problem due to PCMs low thermal conductivity. Researchers are proposing several methods and approaches to increase the thermal conductivity in Phase change material. Insertion of metal / porous material in PCMs, variety of tube configurations with various materials, shapes and inclusion of high thermal conductive Nano particles in PCM are extensively used research approaches. These methods will have certain drawbacks along with high cost including latent heat fusion, mixing additives in PCMs, diminishing of Natural convection.

Alternative method of heat transfer enhancement was done with the use of micro(1– 1000 micro meter) and macro (above micro meter). Researchers done experiments on organic materials (polymers of less molecular weights) at low temperature (60-130). These PCM with micro encapsulation provided faster charging and discharging rates due to low distance of heat transfer. The other method was PCM Coating. Higher the Phase change material (PCM) to mass of coating proportion results better increase in density of energy storage materials and decrease in cost of storing capacity.

Researchers experiments was also conducted Microencapsulation techniques on ceramic materials to avoid corrosion. This procedure provides a gap between coating and Phase Change Material (PCM) core to provide PCM expansion during the phase changing process. Researchers were developing the encapsulation PCM models to with stand highly corrosive environment at high operating temperature. The developed model will provides volumetric expansion on PCM melting on PCM melting and has to reduce the metal corrosion properties. Sharma et al. [1] researchers built the RT42 PCM in concentrated type PV model and reported an increment of electrical efficiency 7.7%. Brown et al. [2] developed a model integrated with pipe inside the PCM container. The heat generated in PCM will transfer to water flow in pipe and enhance the thermal efficiency 18 to 20%. Smith et al. [3] studies the PV system and suggested that PCM integrated with PV will give best results in electrical conversion efficiency. Atkim and Farid [4] have integrated heat basin through PCM for cooling of PV panel and shown PV electrical efficiency enhancement to 12.97%. Kibria et al. [5] used RT25, RT20 and RT28HC phase change material studied the behavior of system and increase the conversional electrical efficiency 5%. HuanG et al. [6] was established the PVT model with fins and without fins considering Phase change material RT 25. He concluded the fins decreases PV hotness by 3°C.

Ho. et al. [7] invented a model with micro encapsulation PCM and gave the result enhancement of electrical conversion efficiency by 19.16%. Huang [8] was analyzed PVT systems thermal/heat behavior using various (RT21, RT27, RT60, RT71 7 RT2723) combinations yields the better enhancement in thermal extraction of PVT model. Shantikian et. al [9] were analyzed that smaller fin positioning and fin thickness tends to faster PCM melting owing to escalation of quantity / fins surface area. From literature it was observed that extraction heat rate of PCM decreases when it completely melts and it tends to rise in temperature.

PCM ENCAPSULATION

Three main important apprehensions in Phase change material encapsulation.

1. The first apprehension is accommodation of PCM on melting with high volumetric expansion
2. The second type is pressure accumulation due to air enlargement at high temperatures Throughout charging Thermal energy systems
3. Reaction of molten PCM with encapsulation PCM materials of organic, inorganic and various metals will react highly corrosive salts.

A selective coating was required to avoid pressure raise in molten PCM due to air enlargement on heating. By providing flexible coating could expand and contract to allow elevated volumetric growth in molten PCM. Due to this selective polymer coating which is easily available in nature was considered as primary disquiet. Compatible study of material was very important while selecting the coating material.

PCMS HEAT TRANSFER ENHANCEMENT

Earlier studies shown that Phase change materials properties lead to less rate of heat transfer due to its less thermal conductivity, leads to cooling system and heat storage devices inefficient. By considering the above it is necessary to improve PCMs thermal heat removal rate. Researchers work undergoing on various heat transfer enhancement techniques using high conductive nano particles and fibrous materials. Figure 1, 2 and 3 shows the heat transfer enhancement techniques.

POROUS MATERAILS HEAT TRANSFER ENHANCMENT

Porous materials were used to PCMS heat transfer rate enhancement. High thermal

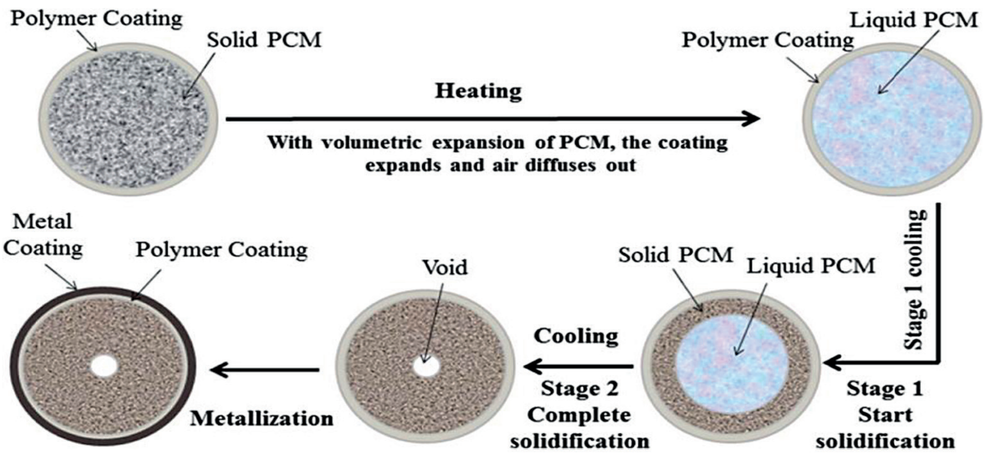

Figure 1. PCM encapsulation model and transformation

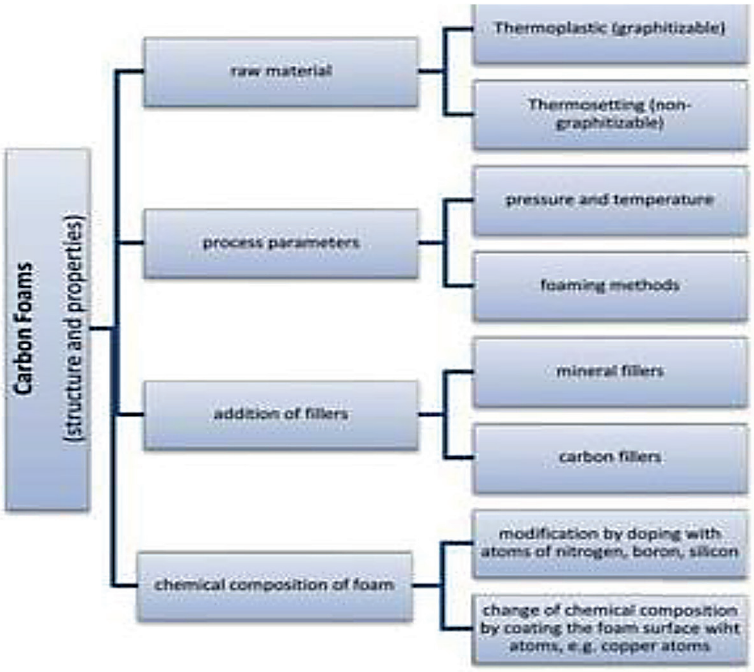

Figure 2. PCM heat transfer enhancement techniques

conductive materials like copper, aluminum, nickel are used. To increase heat transfer surface area porous materials with heat transfer enhancement could be finished with PCMs embed dance in porous materials. Metallic foams are available with different pore densities and porosities which effect the heat transfer rate. Modified Fourier's lae to estimate the thermal conducvity (k).

$$K_{eff} = [Q \text{ x } L] / (T_h - T_c) \qquad (1)$$

where: q, T_h, T_c and K_{eff} are heat flux, high and low temperatures and effective thermal conductivity.

Table 1 shows foaming materials properties and comparison.

Different porous materials used in PCMs

Aluminum foams

Aluminum foam are extensively used for increase the PCMs rate of heat transfer even though it restricts its uses in salts with high melting point. Chen et al [10] studied consequences in PCMs melting rate in existence of metal foam. He used the boltzman thermal lattice model to simulate PCM melting rate in metallic foams. Researchers results shows that PCM melting rate was enhanced by 76% to 78% as compared with pure PCM by which the PCM Composite/ Metallic foam. He also developed the model with paraffin/ Aluminum foam were compared both and gave

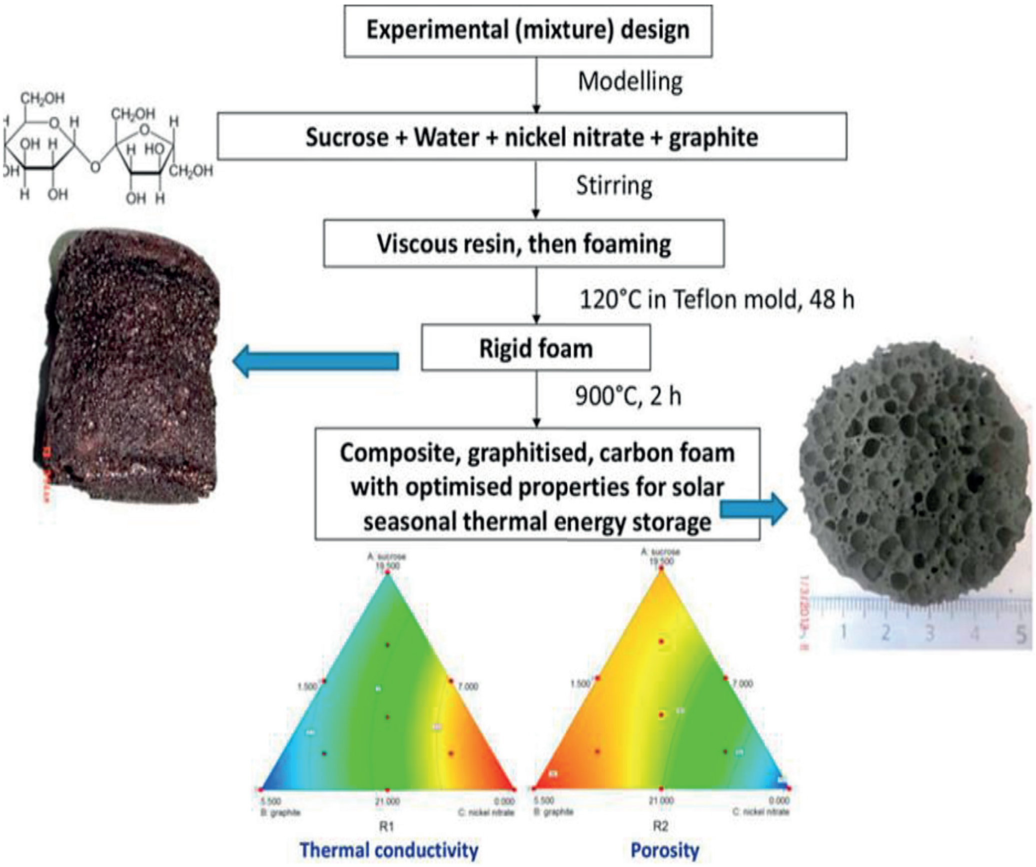

Figure 3. PCM heat transfer enhancement techniques

Table 1. Foaming materials properties and comparison

S.No	Material	Thermal conductivity *K* (*W*/(*m-k*)	T_m(°C)	Density *ρ* (kg/m^3)	Cost/Ton $
1	Aluminum	210-335	655	2700	1999
2	Copper	350-405	1090	8933	6685
3	Nickel	89	1445	8908	11090
4	Graphite	170	4126	2265	1750

conclusions rate of heat transfer was considerably improved by using Al foam / Paraffin compound. Xu et al [11] examined the PCM heat removal rate in concentric tube. He found that alo$_2$ has more heat storage capacity than copper, nearly 4 times. Hong and Herling investigated experimentally warming and chilling time of paraffin in aluminum foam. He used various aluminum foams of different surface densities to improve the thermal conductivity. He found cycle timings of paraffin / aluminum foam elevated to 30 to 40% while comparing with aluminum foam along with increment in surface density. It was also observed that cooling time was delayed while comparing with heating cycle. Atal et al [12] were studied PCMs low thermal conductivity (K) and suitability of heat storage equipment. They studied the aluminum foams with different porosity during PCM solidification and melting and concluded aluminum foam with high porosity has low thermal conductivity than lesser porosity.

Copper foam

Copper material high thermal conductivity and big surface area of porous structure suitable for greater heat transfer applications. This type of copper foams were utilized to increase PCMs rate of heat transfer. Researchers investigated experimentally copper foam or Paraffin composite thermal properties. They observed these PCMs considerably increase the rate of heat transfer by reducing PCM temperature. Reduction in period of charging and discharging were found. Location of foam will effect the heat transfer rate. They observed that placing copper foam in bottom portion of concentric tube was greatest effective up to height of 0.65 to 0.71 1n total height of porous metal saving 28.1% (Figure 4). By examining all porous metallic foams (Aluminium oxide, copper, Ni and Si Carbide) copper foam has four times less heat time for energy storage while comparing with aluminum oxide which it has maximum thermal energy storage time. On other hand silicon carbide heat energy storage density was best due to its low density.

Li et al. [14] Developed a copper foam model using sodium acetate trihydrate composite consuming impregnation behavior and matched the results with pure SAT. It was witnessed modified SAT heat transfer enhancement was 11 times than pure SAT with 92.4% copper foam porosity. Composite PCM took only 40% charging time than that of pure SAT. Qu et al [15] Studied the electronic devices thermal management porosity effect and density of copper foam using PCM composites / Copper foam. They concluded that melting of PCM temperature was lowered while comparing with pure PCM and thermal conductivity effectiveness was enriched to 20 times greater.

Yang et al. [16] evaluated potential effect in various pore density and linearly changeable copper foam porosity on melting and 44 times improvement was observed for porosity of 88.9 % material and also observed improvement of heat transfer 2 times for 97% porosity. He also developed another model to validate and compare the effects of porous media through fin and porous media without fin on PCM thermal behavior with comparison of pure PCM. Vacuum impregnation technique was used to prepare the composites. Researchers inserted the Sodium Nitrate /Potassium Nitrate ($NaNO_3$/KNO_3) PCM in tubular capsule made with AISI 321 and also done experiments on paraffin wax with horizontal hollow brick in rectangular steel shell. He fabricated the steel cell capsules filled with PCM and welded at top of capsule. The biggest challenge in this was at high temperatures corrosion of metal cans due to molten salt. Wand et al. [17] developed the matrix of paraffin/ Copper foam composites and verified copper plays an important role in thermal conductivity enhancement. It was found that storing energy was increased to save the 40% of the time with paraffin wax

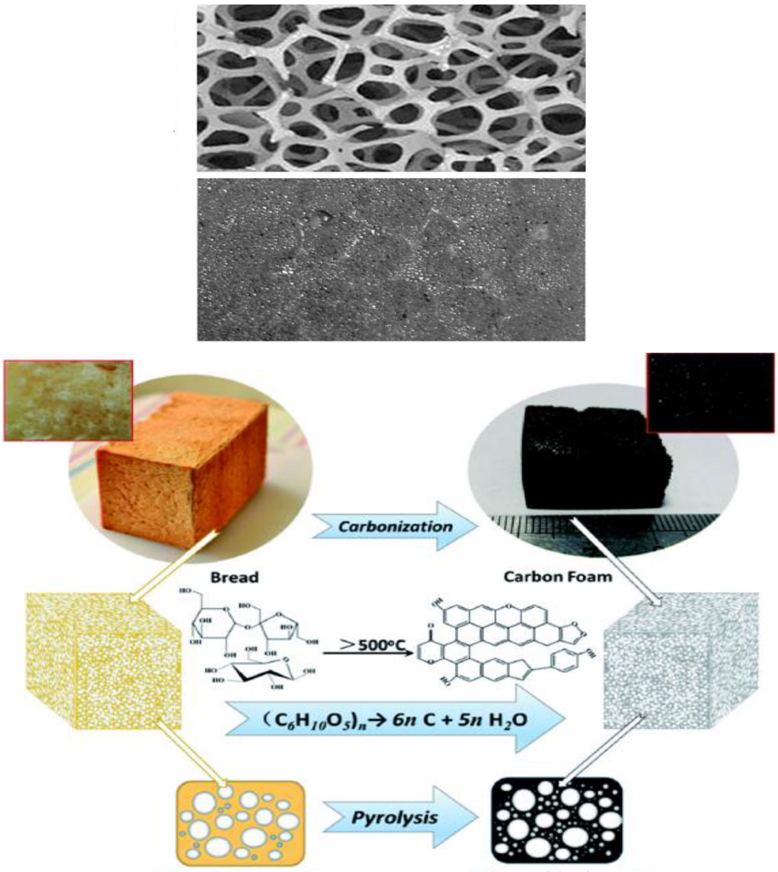

Figure 4. Different foaming materials and micro structure

PCM. Sourav et al.[19] Computed and evaluated the optimization of fin thickness, length, number of fins and spacing of fins.

METHODOLOGY

We developed the PVT panel model without Phase change material (PCM), With PCM, With fins, fins with PCM-1 & PCM 2, Fins PCM with nano material and mixing of pins with Nano material. First developed model contains PV panel, Second model contains a PCM box at back of PV panel, Third system consists of PCM-1 with fins. Fourth PVT model contains PCM-2 with fins, 5th Model contains mixing of PCM-1 & PCM-2 with fins, 6th model PCM-1 & Nano material with fins, 7th model Nanomaterial & PCM-2 with fins and 8th model finned PCM1 & PCM2 Mixing with nanomaterial. Experimental results were discussed here with PCM HS29 without Nano material mixing in PCM. Present paper discusses only with one PCM material (HS 29) with Finned model (Figure 5a, b, c).

PVT system contains a tilt angle denoted by "β". It consists of different layers. In aluminium box fins placed equidistantly to the contained top wall with fin thickness T_f, Fin length L_f and successive fins spacing S_f.

For the developed model some assumptions were considered to experimental work.

1. PCM (Phase change material) was in homogeneous and isotropic in both solid and liquid form which does not effect crystalline segregation / separation.
2. PV panel surface is clean with no dirt, sky conditions were clear and incident soalr irradiation was distributed uniformly on panel.
3. PVT panel & PCM material was not affect with change in temperature (Temperature rise is limited).

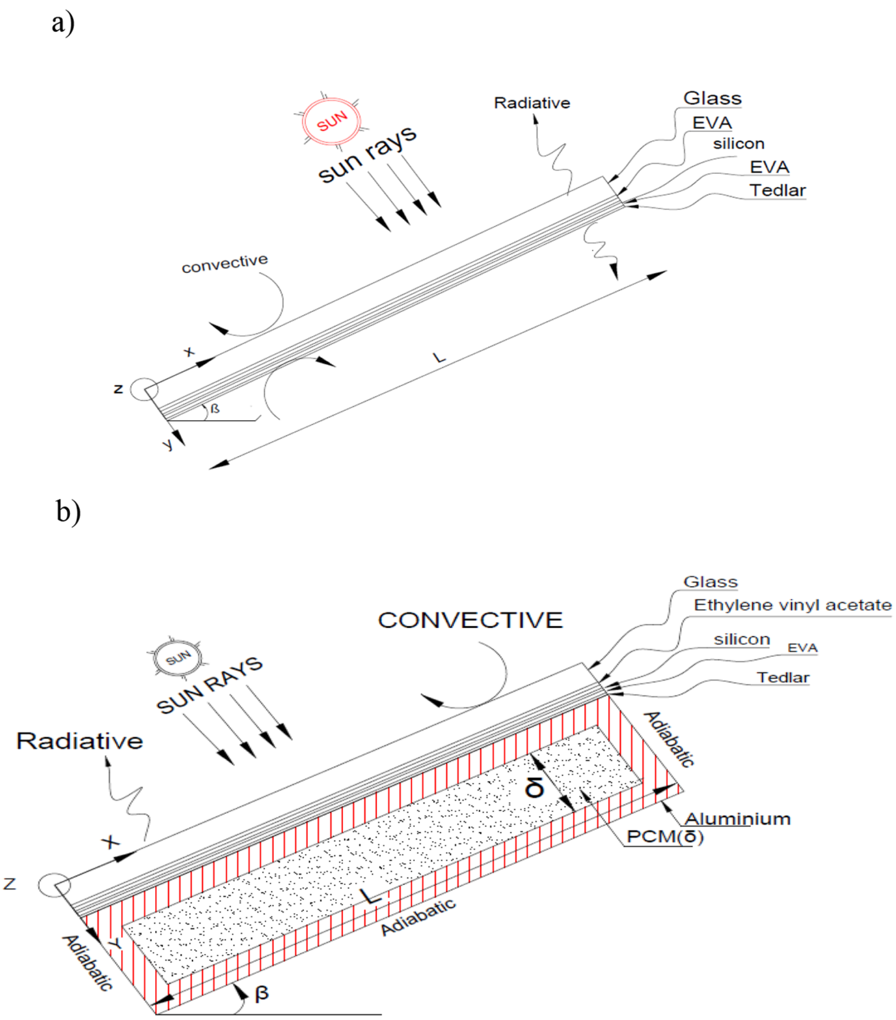

Figure 5. a) PV system; b) PVT model with PCM (PV-PCM); c) PVT model with PCM and Fins (Finned PV-.PCM)

4. PVT model bottom and side surface walls are insulated thermally, heat losses from PVT model was neglected side and bottom.
5. PVT model insulation and symmetry of system along Z-direction, study of 2-D has been carried out.

Radiation coming from the sun solar energy absorbed by PV panel

$$Q = (\alpha\tau)_{eff} \times It \tag{2}$$

where: τ – Transmittivity of glass cover,
α – absorptivity of solar cell absorb plate,
It – Incident solar radiation,
Q – Total radiation transferred.

From the research studies it has been observed that $(\alpha\tau)_{eff}$ is 0.9 was took. Total radiation was not completely converted into electrical energy due to other several reasons.

Experimental & simulation verification

Present model (Fig. 6 & Fig. 7) was verified with experimental measurements using Phase change material. The intensity of radiation (It) 740 W/m^2 and ambient temperature (T_a) 20 °C considered. The top and bottom of system were not insulated where as the side walls were insulated.

RESULTS AND DISCUSSIONS

Experimental model methodology developed to study and analyze thermal response

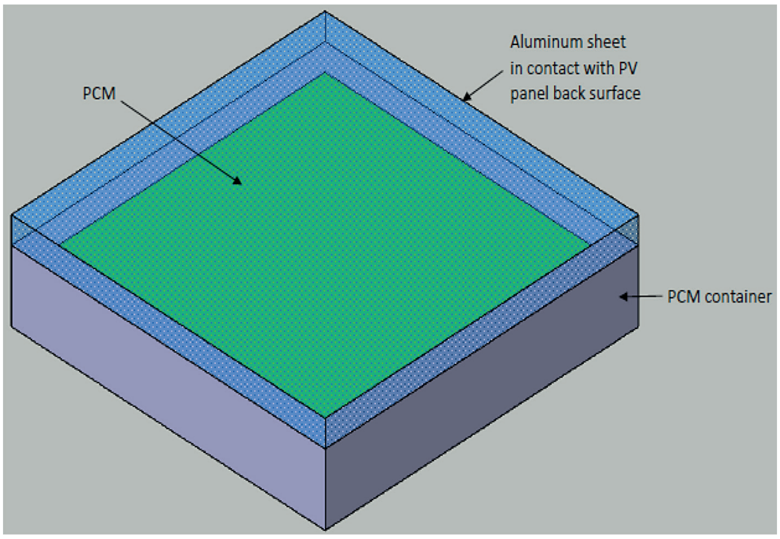

Figure 6. Container with bulk PCM without fins

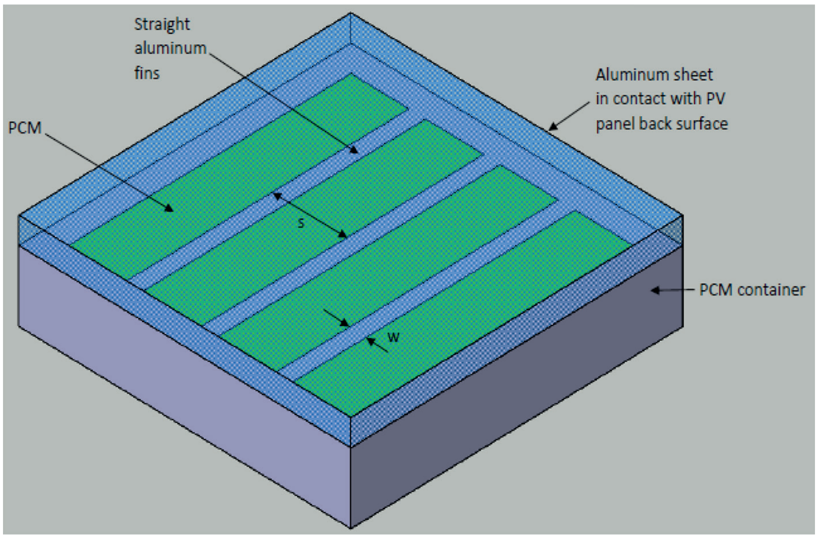

Figure 7. Container with bulk PCM with fins

Table 2. Design model components properties

Material	Heat capacity (kJ/(kg.K))	Density (kg/m^3)	Thickness (*t*) (mm)	Thermal conductivity (*W/m.k*)
Glass	0.51	3002	3.0	1.9
Silicon	0.69	2331	0.3	149
EVA	2.2	965	0.5	0.36
Aluminum	0.9	2675	4	212
Tedler	1.25	1200	0.1	0.21

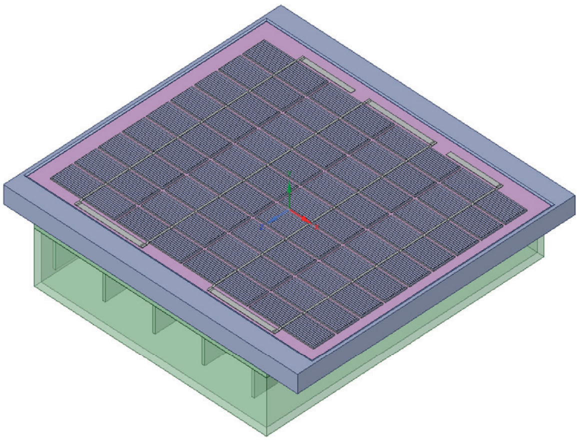

Figure 8. Modelled aluminium finned PVT system I

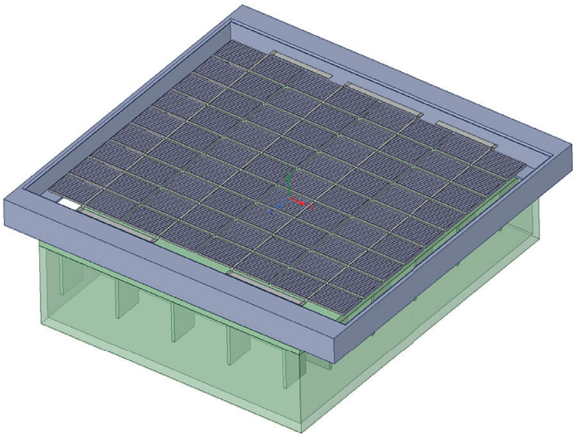

Figure 9. Modelled aluminium finned PVT-PCM system II

of PV system, PV-PCM, PV-Finned PCM system in terms of temperature variations with time. Optimum range of spacing between fins, Fin length, Fin thickness and depth of PCM box were examined. Optimal suitable fin dimensions with modeled contained depth for different intensity of solar radiations to cool the PV panel have been calculated. The impression of Fin dimensions on appropriate depth was examined. The following Parameters were considered for calculations to built the model (Table 2, Fig. 8, Fig. 9).

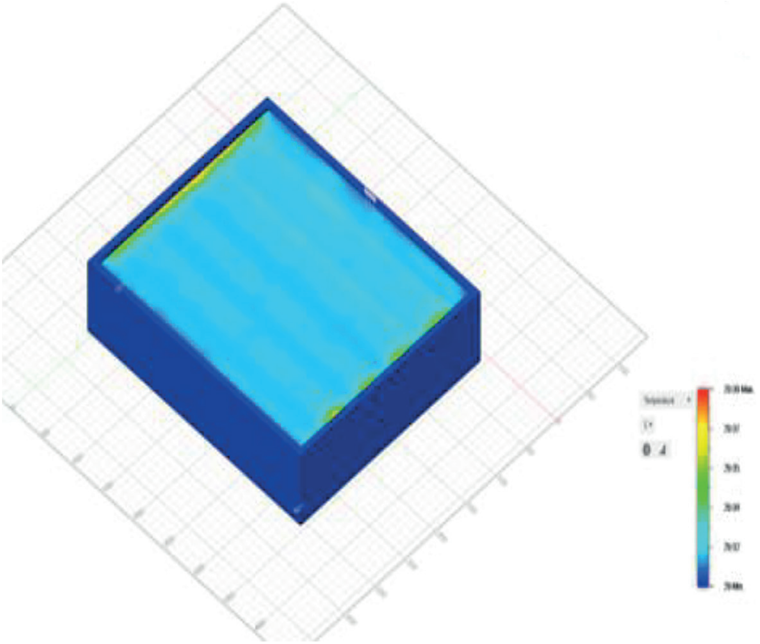

Figure 10. Temperature distribution in finned model

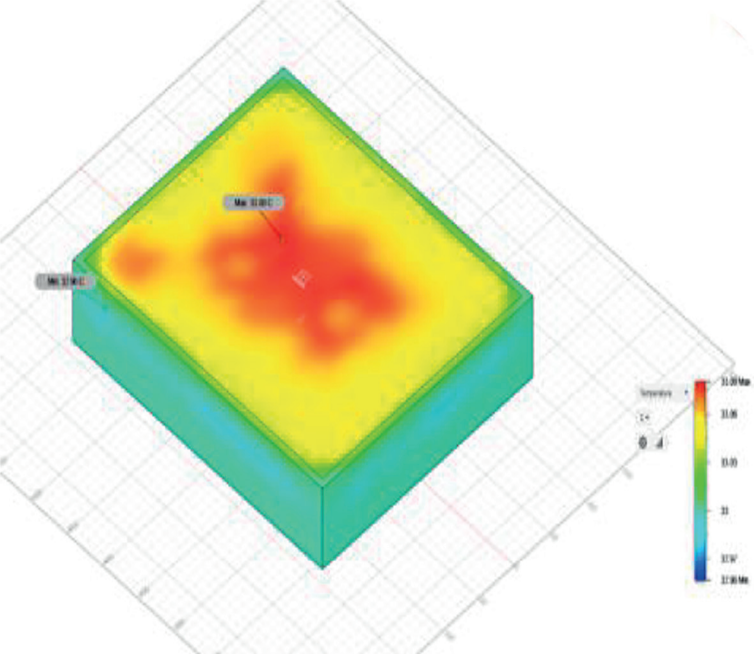

Figure 11. Temp distribution in PV system (without fins)

The deviation in middling PV temperature w.r.t to time in PV-PCM finned model has shown in graph plotted between PV Temperature with variation with time in Fig. 15. The outcomes recommend that there is an early rush in PV temperature which ultimately drenches and then ruins unceasing for noteworthy period (Fig. 10, Fig. 11). It was also observed an increment in temperature another time outside a point. This is because firstly, the PCM heat extraction rate was low due to its phase in solid. Whenever the PCM will start melting it absorbs the latent heat from photovoltaic cell without increase in its panel temperature. When PCM is completely melts and absorbs total latent heat perceived in decrement of rate of heat extraction because thermal heat may be removed only sensible heat, tends to additional escalation of temperature in PV panel.

PCM contained optimum depth design

The deviations in PV-PCM finned model average temperature was showing Fig. 12 for various depths of phase change material. It was observed PCM container box depth increment will increase the volume of the cooling in PVT panel in relation of time duration increases. The results shown that beyond the certain PCM depth limit the optimum cooling was only 0.8 °C.

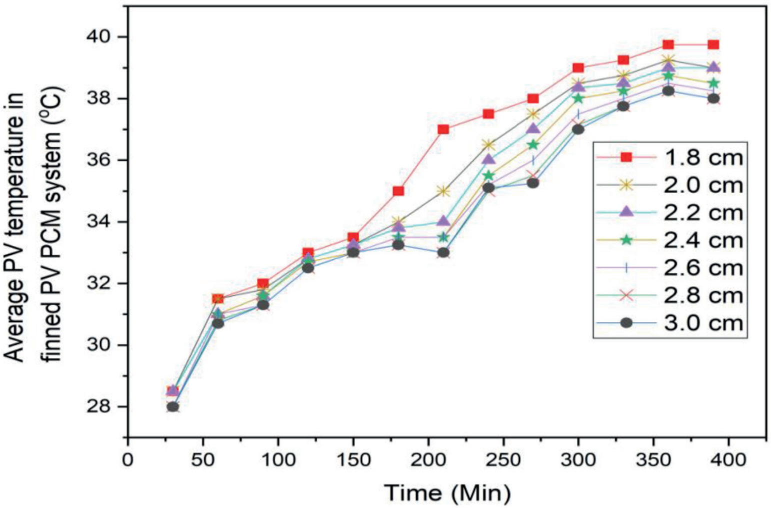

Figure 12. PVT-finned with PCM with various depths

PCM Model fin spacing effect

The optimum depths were calculated at different solar intensity of radiation. It was found that rather than keeping the large amount of PCM in container, spacing b/w fins is smaller, increment in number of fins will give the better heat extraction rate in PCM was higher and its melting in less time duration. The results also stated that if fins spacing increase at a certain point, it reduces PCM container convective energy flow and leads to increment in conductive energy flow leads to reduction of melting rate with reduction in fin spacing (Fig. 13).

Influence of fins thickness and material in PVT model

PV-PCM finned system temperature patterns were analyzed for various depth of PCM container. Optimum depths were designed at different fin thickness and numerous solar irradiance level were shown. Our experimental studies showed that thicker fins, PCM box depth are larger causes fast PCM melting rate due to extraction of heat rate higher, ultimately required more PCM depth for more PV cooling effectiveness (Fig. 14).

Fin shape and nanomaterial

The shape, size, and Nano particles dispersed within the PCM must be taken into account in order to achieve better property improvements such as thermal conductivity and specific heat capacity. Selection of Nanomaterial, shape will be critical and can be done by various studies, experiments and optimum selection plays important role in thermal enhancement.

Fins effect on standard deviation of PV temperature along height

PV panel temperature rise results the same of PCM melts, the solid pattern is moved to bottom pushing the liquid portion to box upwards. It

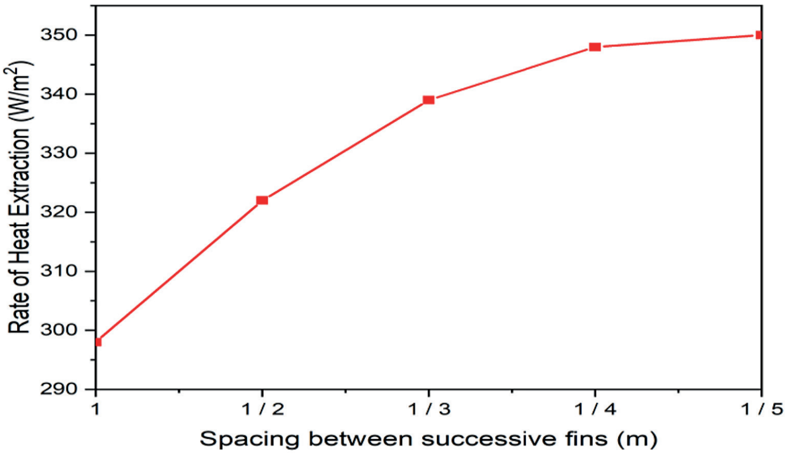

Figure 13. Fins spacing in PCM

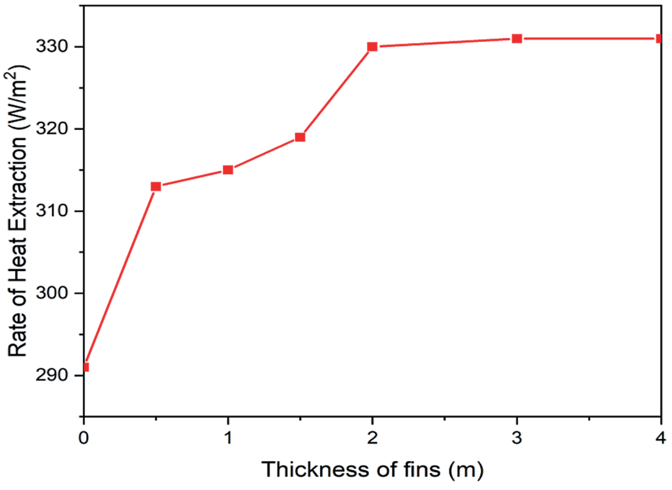

Figure 14. PVT-PCM fins thickness

tends to thermal behavior or variation inside of PCM container beside the height results the PV temperature variations. Standard deviation of PV Temperature along height was determined for different spacing between fin shown in Fig. 13

Experimental results showing that fins spacing reduces, the standard deviation of PV temperature reduces. This is because of displacement of PCM portion is more restricted because less space between fins which tends to min deviations of temperature in PCM container, beside container height causing smaller standard PV temperature variations. Experimental studies stated that when Phase change material becomes completely liquid form, variation of temperature with height decreases (Fig. 15).

PVT model optimum spacing between fins

The dissimilarities of PV system average temperature and various spacing between fins and corresponding phase change material heat extraction rate was present in Fig. 13. Simulation study results shows decrease in fin spacing, PV temperature decreases. It is due to decrease in spacing, system fins number increase which enhances the heat extraction as shown in graph leads to PVT temperature decrement. The studies shows that fin spacing beyond 24 cm does not tend in noteworthy reduction of PV temperature. The optimum arrangement distance between fins is 24 cm.

Effect of length of PV-fins in PVT model

The studies shows PV temperature decreases with increase in fins length. It occurs due to heat extraction rate faster from PV in case of longer size fins. The results shows there was predominant decrease in PV temperature when fin length becomes "δ" (Depth of Container) as related to smaller fin length (Fig. 16). When PV PCM fin length was

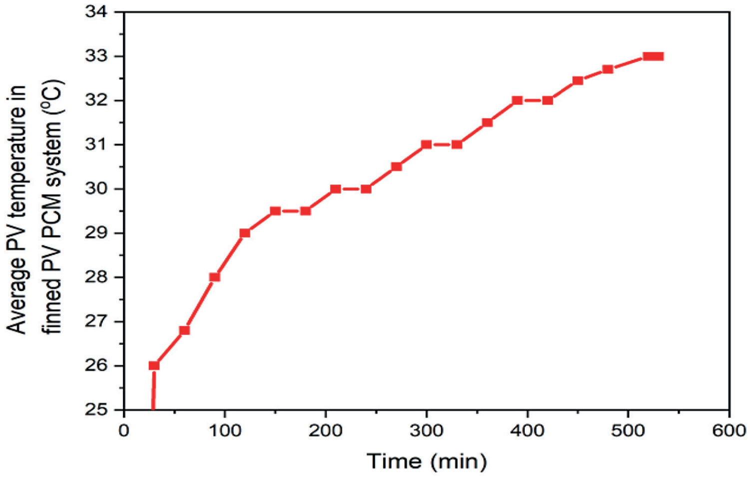

Figure 15. PVT-finned with PCM variation with time

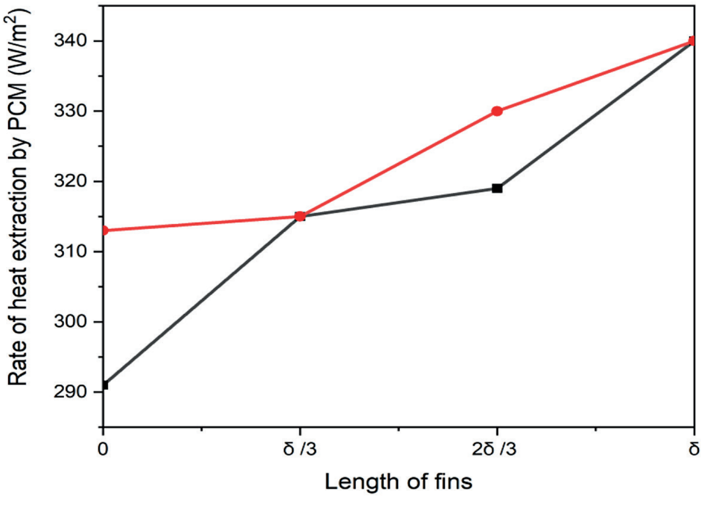

Figure 16. PVT-finned with PCM variation with fin length

"δ", the top of fin touched the PCM container box bottom part. PCM box made with aluminum high thermal conductivity the temperature at bottom increases and then PCM starts removing thermal heat from box bottom also in addition to top of fins. Due to this it enhances the better rate of heat extraction of PCM results the optimum cooling rate of PVT model. By considering all the above length of fin is equal to PCM container box depth.

Optimum thickness of fins

Variation of fin thickness and simultaneous heat extraction rate of PCM was presented in Fig. 14. Suggested results shows that decrement in PV temperature with increase of fin thickness. It is due to extraction of heat rate will be more, when thickness of fins was increased. It results the optimum thickness of fins range were 1.8 to 2 mm to decrease in PV panel temperature.

CONCLUSIONS

Experimental model was developed for analyzing and accomplishment of Photo Voltaic (PV), Photo voltaic – Phase Change Material (PV-PCM) and Photo voltaic – finned PCM thermal behavior of heat through conduction (*k*), convection (*h*) along with radiation. It was analyzed temperature deviations of PV system with respect to time was modulated beside with length of fin, fin thickness and spacing between fins. The aim of the study was to maintain minimum PV temperature, the better fin dimensions were calculated and validated. Our results shows that increment of PCM material in PCM box will results the lead in increment of cooling rate in PVT model. The present work studies were computed at various incident intensity of solar radiation with optimum PCM quantities. The present wok not includes the PCM's crystalline segregation which will decrease the speed in transfer of heat in PCM. It was also assumed fin was touched the back of PCM box. The present wok not includes the PCM's crystalline segregation which will decrease the speed in transfer of heat in PCM. It was also assumed fin was touched the back of PCM box. Fins material and its conductivity places an important role in heat removal enhancement. in PCM modeled box depth with different fin length, thickness and intensity of solar radiation were computed, the conclusions are as mentioned below. Phase change material required higher in quantity, for larger length fin to maintain cooler photo voltaic panel. Fin length higher can sustain the lower temperature of Photo voltaic. Optimum fin length was one which touches the PCM box bottom. Upholding fins distance smaller spacing larger PCM quantity required to preserve PV panel with low thermal temperature due to PCM melt rate in lesser extent owing to better rate of heat removal. Lesser distance among fins will tends to preserve the PV panel cooler. Though, reduction of spacing beyond 24 cm will not rise to measurable enhancement. For higher thickness of fins, larger quantity of PCM was required for PV cooling rate enhancement. Higher fin thickness tends to inferior PV thermal temperature. Even though fin thickness outside 2 mm will not leads to any enhancement of thermal behavior to extract the heat.

REFERECES

1. Sharma S., Tahir A., Reddy K.S., Mallick T.K. 2016. Performance enhancement of a Building-Integrated Concentrating Photovoltaic system using phase change material. Sol Energy Mater Sol Cells, 149, 29–39.
2. Huang M.J., Eames P.C., Norton B., Hewitt N.J. 2011. Natural convection in an internally finned phase change material heat sink for the thermal management of photovoltaic. Sol Energy Mater Sol Cells, 95, 1598–1603.
3. Smith C.J., Forster P.M., Crook R. 2014. Global analysis of photovoltaic energy output enhanced by phase change material cooling. Appl Energy, 126, 21–28.
4. Atkin P., Farid M.M. 2015. Improving the efficiency of photovoltaic cells using PCM infused graphite and aluminium fins. Sol Energy, 114, 217–228.
5. Kibria M.A., Saidur R., Al-Sulaiman F.A., Aziz M.M.A. 2016. Development of a thermal model for a hybrid photovoltaic module and phase change materials storage integrated in buildings. Sol Energy, 124, 114–123.
6. Huang M.J., Eames P.C., Norton B. 2004. Thermal regulation of building-integrated photovoltaics using phase change materials. Int J Heat Mass Tran, 47, 2715–2733.
7. Ho C.J., Tanuwijava A.O., Lai C.M. 2012. Thermal and electrical performance of a BIPV integrated with a microencapsulated phase change material layer. Energy Build, 50, 331–338.
8. Huang M.J. 2011. The effect of using two PCMs on the thermal regulation performance of BIPV systems. Sol Energy Mater Sol Cells, 95, 957–963.
9. Shatikian V., Ziskind G., Letan R. 2005. Numerical investigation of a PCM-based heat sink with internal fins, Int J Heat Mass Tran, 48, 3689–3706.

10. Chen Z., Gao D., Shi J. 2014. Experimental and numerical study on melting phase change materails in metal foams at pore scale, int. J.heat Mass Transf., 72, 646– 655.
11. Xu Y. et.al. 2015. Evaluation and optimization of melting performance for a latent heat thermal energy storage unit partially filled with porous media. Appl. Energy, 193(920170), 84–95.
12. Hong S.T., Herling D.R. 2006. open-cell aluminum foams filled with phase change materials as compact heat sinks. Scriptia materials, 55(10), 887–890.
13. Martinelli M. et al. 2016. Experimental study of Phase change thermal energy storage with copper foam, Appl. Therm Eng., 101, 247–261.
14. Li T. et al. 2015. Experimental investigation on copper foam/hydrated salt composite Phase change material fore thermal energy storage, int. J. heat mass Transf., 115(920170), 148–157.
15. Qu Z. et al. 2012. Passive thermal management using metal foam saturated with Phase change material in heat sink. Int. Commun. Heat Mass Transfer, 39(10), 1546–1549.
16. Yang J. et. Al. 2015. Numerical analysis on thermal behavior of Solid-liquid phase change within copper foam with varying porosity, int. J.Heat Mass Transf., 84, 1008–1018.
17. Wang C., et al. 2016. Heat transfer enhancement of Phase change composite material: copper foam/paraffin. Renew. Energy, 96, 960–965.
18. Khanna S. et al. 2018. Optimization of finned solar Photovoltaic PCM System. International journal of Thermal science, 130, 313–322.
19. Kameswara Rao D. et al. 2021. Photovoltaic/Thermal (PV/T) System Performance Effects Using conventional/ / Modern Cooling Techniques with and Without PCM Lecture notes in mechanical engineering springer, 26, 651–665.